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BUREAU OF MINES
JAMES BOYD, DIRECTOR

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LIMESTONE AS A BUILDING MATERIAL

BY

OLIVER BOWLES AND NAN C. JENSEN

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LIMESTONE AS A BUILDING MATERIAL[1]

By Oliver Bowles[2] and Nan C. Jensen[3]

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INTRODUCTION

Stone, the foundation of the continents and the floor of the oceans, is one of the most substantial and enduring of all substances that constitute the material universe. Stone furnished rude shelter for aboriginal man, and through all succeeding ages it has provided a lasting and serviceable structural material. Limestone is one of the most widely used building stones.

DEFINITION

Limestone consists essentially of calcium carbonate ($CaCO_3$). Rocks classed commercially as building limestones may contain varying quantities of magnesium carbonate. If more than 10 percent is present, they are termed "magnesian" or "dolomitic" limestones; if the magnesium carbonate content

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7416."

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approaches 45 percent, the rock consists essentially of the double carbonate of lime and magnesia ($CaCO_3.MgCO_3$), the mineral dolomite. When used as dimension stone, dolomite is classed commercially as limestone.

VARIETIES

Limestones are classified according to the nature of their impurities. "Siliceous" or "cherty" limestone contains considerable silica and argillaceous limestone clay or shale. A "ferruginous" limestone contains iron compounds, which usually give it a buff, reddish, or yellowish color. The most widely used building limestones are "oolitic" because of their resemblance to fish roe. They consist of small rounded grains of lime carbonate having a concentrically laminated structure.

Limestones consist chiefly of the shells of sea animals. Usually they have been comminuted so completely that no trace of organic structure remains. Some deposits, however, have been formed under conditions that have left the shells almost intact, or at least in fragments well-preserved enough to indicate their character and origin; these are known as fossiliferous limestones. "Coral," "crinoid," and "coquina" are common types.

"Travertine" is a variety of limestone that is regarded as a product of chemical precipitation from hot springs. Details regarding this type of limestone are given in another Bureau report.4/

PRODUCTION

Limestone is the most widely used of all rocks. Its products fall into two main classes: (1) crushed and broken stone, and (2) dimension stone. The former is by far the larger class. Millions of tons of crushed and pulverized limestone are sold for road-building, concrete aggregate, fluxing stone, agricultural stone, and for many other uses. The second class, dimension stone, includes blocks of stone that are generally cut to definite shapes and often to specified sizes. Small quantities of limestone are shaped into curbing, flagging, and paving stones, but by far the largest part of the dimension-limestone output consists of building stone. The following table shows production of dimension limestone over a series of years. It may be observed that the value of building stone ranges from 72 to 96 percent of the total. Rubble, although used for building purposes, is classed separately.

Material classed as building stone in table 1 may be subdivided according to its character and the extent to which it is manufactured into finished products. Table 2 shows the quantity and value of the various classes of building limestone sold during recent years.

Rough construction stone, the first of the three groups of building stone in this table, is sold mostly by the ton for rustic building of many kinds. It overlaps to some extent the material classed as rubble in table 1.

4/ Bowles, Oliver, Onyx Marble and Travertine: Bureau of Mines Inf. Circ. 6751R, 1940, pp. 9-11.

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TABLE 1. - Dimension limestone sold or used by producers in the United States, 1921-45, by kinds

Year	Building stone[1]			Rubble		Flagging, curbing, and paving			Total	
	Approximate short tons	Cubic feet	Value	Short tons	Value	Approximate short tons	Cubic feet	Value	Approximate short tons	Value
1921 ..	621,500	8,019,700	$7,886,586	188,000	$280,067	2,700	33,930	$33,804	812,200	$8,200,457
1922 ..	955,540	12,617,380	12,418,873	286,340	470,264	(2/)	(2/)	(2/)	1,241,880	12,889,137
1923 ..	1,099,390	14,639,950	16,221,095	327,180	484,771	6,600	75,070	46,830	1,433,170	16,752,696
1924 ..	1,097,530	14,456,320	15,805,680	392,180	623,844	5,560	69,010	78,264	1,495,270	16,507,788
1925 ..	1,204,550	15,983,800	16,092,079	324,630	513,387	11,730	129,730	98,587	1,540,910	16,704,053
1926 ..	1,394,220	18,537,950	20,391,597	254,240	476,545	12,800	167,780	135,882	1,661,260	21,004,024
1927 ..	1,278,620	17,340,690	18,820,045	226,280	400,790	18,670	223,370	134,360	1,523,570	19,355,195
1928 ..	1,370,940	17,641,370	20,193,963	365,920	705,723	34,400	322,560	205,724	1,771,260	21,105,410
1929 ..	1,312,820	17,864,700	20,649,257	352,480	693,678	37,940	471,880	158,266	1,703,240	21,501,201
1930 ..	1,152,780	15,682,720	18,535,293	756,470	623,100	27,760	346,040	137,801	1,937,010	19,296,194
1931 ..	872,630	11,706,840	10,858,697	229,510	296,426	15,220	166,260	85,175	1,117,360	11,240,298
1932 ..	545,340	7,414,130	7,028,224	84,570	84,308	10,870	122,000	38,332	640,780	7,150,864
1933 ..	465,480	6,599,250	6,416,223	79,060	94,046	6,310	78,610	32,134	550,850	6,542,403
1934 ..	386,420	5,176,860	3,391,455	190,080	179,791	9,010	116,610	49,886	585,510	3,621,132
1935 ..	529,810	6,871,320	2,700,747	185,790	276,569	7,240	93,700	44,229	722,840	3,021,545
1936 ..	585,330	7,735,520	4,662,716	204,700	181,415	14,680	178,000	74,053	804,710	4,918,184
1937 ..	592,340	7,736,140	5,096,535	107,550	136,028	13,690	167,950	76,806	713,580	5,309,369
1938 ..	538,710	7,084,410	4,667,496	155,370	194,621	10,000	95,880	74,560	704,080	4,936,677
1939 ..	822,670	10,730,020	6,402,680	221,060	189,597	16,940	168,480	85,565	1,060,670	6,677,842
1940 ..	446,810	5,902,010	3,599,559	616,250	582,257	19,070	236,530	78,149	1,082,130	4,259,965
1941 ..	391,370	5,154,730	3,277,723	405,220	439,479	17,030	210,290	62,794	813,620	3,779,996
1942 ..	233,710	3,224,500	1,791,567	221,180	324,097	8,080	100,790	28,823	462,970	2,144,487
1943 ..	106,430	1,354,700	574,220	124,420	198,112	6,230	76,960	25,516	237,080	797,848
1944 ..	101,160	1,309,100	539,707	54,200	60,833	6,280	76,250	22,789	161,640	623,329
1945 ..	259,420	3,411,730	2,406,326	69,780	73,413	5,280	65,060	25,272	334,480	2,505,011

1/ Includes small quantities of monumental stone.
2/ Included with building stone.

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TABLE 2. - Building limestone[1/] sold or used by producers in the United States, 1921-45, by kinds

Year	Rough					Finished (cut and sawed)		Total		
	Construction			Architectural						
	Short tons	Approximate cubic feet	Value	Cubic feet	Value	Cubic feet	Value	Approximate short tons	Cubic feet	Value
1921 ...	183,000	2,153,000	$253,786	2,458,780	$1,699,783	3,407,920	$5,933,017	621,500	8,019,700	$7,886,586
1922 ...	210,690	2,421,800	271,343	4,352,030	2,577,416	5,843,550	9,570,114	955,540	12,617,380	12,418,873
1923 ...	210,310	2,415,300	238,805	5,031,840	3,184,932	7,192,810	12,797,358	1,099,390	14,639,950	16,221,095
1924 ...	239,680	2,691,870	304,911	5,012,520	3,231,613	6,751,930	12,269,156	1,097,530	14,456,320	15,805,680
1925 ...	270,970	3,186,900	335,842	5,728,830	3,661,276	7,068,070	12,094,961	1,204,550	15,983,800	16,092,079
1926 ...	288,760	3,361,470	380,131	6,161,390	3,837,081	9,015,090	16,174,385	1,394,220	18,537,950	20,391,597
1927 ...	206,480	2,575,800	292,792	5,953,780	3,832,414	8,811,110	14,694,839	1,278,620	17,340,690	18,820,045
1928 ...	211,780	1,730,500	279,434	5,255,690	3,268,140	10,655,180	16,646,389	1,370,940	17,641,370	20,193,963
1929 ...	178,490	2,242,050	280,564	6,192,550	3,779,639	9,430,100	16,589,054	1,312,820	17,864,700	20,649,257
1930 ...	131,410	1,611,700	194,550	6,134,250	3,278,346	7,936,770	15,062,397	1,152,780	15,682,720	18,535,293
1931 ...	220,970	2,733,760	317,852	3,594,270	1,574,720	5,378,810	8,966,125	872,630	11,706,840	10,858,697
1932 ...	50,580	609,630	77,872	3,275,830	1,334,095	3,528,670	5,616,257	545,340	7,414,130	7,028,224
1933 ...	78,790	961,800	108,100	2,298,620	902,911	3,338,830	5,405,212	465,480	6,599,250	6,416,223
1934 ...	156,000	2,018,200	179,337	1,345,350	533,839	1,813,310	2,678,279	386,420	5,176,860	3,391,455
1935 ...	293,050	3,627,500	310,878	1,795,360	567,041	1,448,460	1,822,828	529,810	6,871,320	2,700,747
1936 ...	156,970	1,950,690	272,164	2,862,910	1,033,688	2,921,920	3,356,864	585,330	7,735,520	4,662,716
1937 ...	191,660	2,281,090	380,324	2,563,410	1,021,753	2,891,640	3,694,458	592,340	7,736,140	5,096,535
1938 ...	166,260	2,006,460	316,772	2,455,580	895,791	2,622,370	3,454,933	538,710	7,084,410	4,667,496
1939 ...	320,640	3,872,640	424,230	3,367,550	1,426,020	3,489,830	4,552,430	822,670	10,730,020	6,402,680
1940 ...	103,470	1,265,060	174,148	2,344,440	982,842	2,292,510	2,442,569	446,810	5,902,010	3,599,559
1941 ...	106,290	1,319,870	367,995	1,651,910	666,323	2,182,950	2,243,405	391,370	5,154,730	3,277,723
1942 ...	96,610	1,332,570	209,313	866,540	257,212	1,025,390	1,325,042	233,710	3,224,500	1,791,567
1943 ...	52,680	635,090	76,468	421,930	139,928	297,680	357,824	106,430	1,354,700	574,220
1944 ...	47,360	578,530	58,076	426,640	168,855	303,930	312,776	101,160	1,309,100	539,707
1945 ...	92,090	1,113,590	138,825	1,123,290	578,035	1,174,850	1,689,466	259,420	3,411,730	2,406,326

1/ Includes small quantities of monumental stone.

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Rough architectural limestone is that which is sold principally to independent fabricating mills that buy their rough stock from quarry operators.

Material classed as finished stone is that fabricated in mills operated by quarry companies. The totals in the last three columns of table 2 are made up partly of rough blocks and partly of finished products. The addition of semifinished to finished stone is an unfortunate combination but is unavoidable because Bureau of Mines statistics are based upon original sales of producers in whatever form they market their products. The total finished-product value of building limestone sold by both independent mills and fabricating plants operated by quarry companies is probably about twice the value given in the total-value column of table 2.

Statistics of production appear annually in the chapters on Stone from the Minerals Yearbook, published annually by the Bureau of Mines. Copies of these chapters may be obtained from the Superintendent of Documents, Washington 25, D. C., for 10 cents each.

REQUISITE QUALITIES

Although innumerable limestone deposits occur throughout the country, only a few consist of rock that will satisfy the exacting requirements of dimension stone. Deposits with irregular or closely spaced joints are not suitable, because large blocks free from cracks or lines of weakness are generally demanded. Limestones display great variation in physical properties, such as texture, porosity, hardness, strength, and color, and upon these depend their adaptability and value as dimension stone. The chemical composition also varies in different types of stone, but although this may have some bearing on the quality of the material, it is of little consequence in this branch of the industry.

Dimension stone must have adequate tensile and compressive strength. Sound structural limestone suitable in other respects is almost invariably strong enough for any use; in fact, the strength of ordinary stone far exceeds the requirements for safety. However, it is generally conceded that rock disintegrates and weakens more readily when under severe stress, and therefore a factor of safety of 20 is demanded; that is, stone must be able to resist a crushing stress 20 times as great as that to which it will be subjected when placed in a wall. Tests of transverse strength - that required to sustain a load applied at the middle of a bar of stone supported at the ends - are more important than crushing-strength tests.

The suitability of a limestone depends to quite an extent on the degree of cementation of the grains. If they are loosely coherent, the limestone is "earthy" or "friable." Material in which they adhere closely and strongly is "compact." Most limestones may be regarded as durable enough for all ordinary uses, but the heavier or compact types are most desirable. Weight per cubic foot is a fair index of durability.

Hardness has a direct bearing on workability. Although all limestones are soft enough to be scratched easily with a knife the presence of flint or other siliceous minerals may make quarrying or milling more difficult. For

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stone that is to be subjected to abrasion, such as paving, curbing, floor tile, or stair treads, hardness is a requisite quality, whereas it is not necessary in material used for walls or decoration.

For most uses, uniformity of texture and color is preferable. Coarse texture was once regarded as a serious imperfection, but tests have shown that coarse-grained stone compares favorably in durability and strength with fine-textured material, and modern demands for variety have led to its wider use.

Limestones are of many colors, ranging from white to black. Colors other than white are caused by impurities in the stone. Certain constituent minerals, such as pyrite, marcasite, or siderite, may oxidize by weathering and cause surface stains, which are serious blemishes. The colors of some limestones change with age, and although this is not always objectionable, permanence of color is usually preferred. Choice of color depends on environment, individual taste, or prevailing fashion. Brown, buff, gray, or white limestones are usually chosen for building purposes. White and other light colors are not desirable for smoky cities. Variegated stone, sawed and rock-faced, is now popular for residences.

ECONOMIC CONDITIONS

A deposit of limestone may meet all the general requirements as to quality, but development may not be justified from a business standpoint. Availability of markets is an important consideration. Stone being a heavy product, the freight charge is a substantial part of the delivered price, and consequently a location within easy reach of large centers of building construction is to be desired. Transportation facilities, by truck, rail, or water, should be favorable. The best rates are obtained where two or more competing lines are easily accessible. Cost of production has definite bearing on market range, for a low-cost product can absorb a relatively high freight charge and thus compete successfully in distant markets with high-cost local stone. Quarry conditions should be considered carefully before development is undertaken. A thick overburden of soil or rock or a heavy flow of water requiring excessive pumping may constitute large items in the cost of production. Availability of labor, living conditions, and prevalent wage levels are other matters that deserve attention.

TYPES OF PRODUCTS

Limestone used in construction work is of four main types - cut or finished stone, ashlar, rough building stone, and rubble. The largest quantity consumed is in the form of cut or rough-hewn blocks.

Cut Stone

Cut stone includes all forms of finished blocks, columns, sills, moldings, balusters, or special designs. It is the most expensive type because usually the blocks are accurately shaped and sized in accordance with detailed

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drawings. Cut blocks may be used for entire buildings or only for certain parts, as window sills, trim, cornices, or base course. Massive blocks are used for bridges, dams, sea walls, and similar structures. Columns and balusters are used on both the inside and outside of buildings. For decorative purposes blocks may be elaborately carved.

Ashlar

Ashlar is a term applied to small rectangular blocks having sawed, planed, or rock-face surfaces. Several types are used. "Even-course" ashlar consists of blocks usually 3 or 4 inches thick, of uniform height for each course, though succeeding courses may be thicker or thinner. They may be of uniform or random lengths. Two or more unit thicknesses may be used, several of the smaller sizes giving the same height as one of the larger blocks. "Random" ashlar consists of blocks that may be fitted together in a wall having irregular and unequally spaced joints.

Ashlar is particularly adaptable for residences, and costs much less than cut stone. Its production is also economically advantageous to producers, for small material that would otherwise be wasted may be thus utilized.

Rough Building Stone

Rough building stone consists of rock-faced masses of various shapes and sizes. It is used extensively for chimneys, basements, or entire walls of residences and to some extent for public buildings, bridges, fences, and the more ornamental types of retaining walls.

Rubble

The term "rubble" is generally applied to irregular fragments having at least one good face. It is the crudest form of building stone. Many years ago rubble constituted a distinct type of stone that was used principally for foundations and other rough walls, but concrete has gradually replaced stone for such types of construction. On the other hand, fashion in architecture was changing meanwhile from smooth and formal walls to rougher and more variegated styles, with the result that rubble has attained more dignified uses. From its lowly cellar-wall position it has been elevated to share with cut stone a more prominent place in many types of construction. Therefore, although rough construction stone and rubble were at one time fairly distinct types, they are gradually merging, and it becomes increasingly difficult to differentiate them.

CENTERS OF PRODUCTION

Although limestone occurs in every State, deposits suitable for dimension stone where conditions are favorable for development, exist in only a few States.

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Alabama has been an important producer of oolitic limestone, but operations were suspended owing to war conditions. The largest development is near Rockwood, Franklin County, where a large mill is provided with the most modern equipment. Shell limestones are quarried for building purposes in Volusia and Pinellas Counties, Fla.

The largest quarry center for building stone in the United States is the oolitic-limestone district near Bedford, Lawrence County, and Bloomington, Monroe County, Ind. Several large companies normally operate quarries and mills, and several others operate finishing mills only. In 1945 Indiana supplied 46 percent of the total quantity and 81 percent of the total value of building limestone produced in the United States. Before the recent World War these proportions were higher.

The Salem formation, which provides the stone, is a massive bed ranging from 25 to nearly 100 feet in thickness. It extends from the Ohio River northward through Salem, Bedford, and Bloomington to a point north of Greencastle, a distance of about 125 miles. Buff and gray limestone predominate. The stone is easily worked when first quarried but becomes harder when seasoned.

Warren County, Ky., was a prewar source of oolitic limestone similar to that produced in Indiana. The finishing mills were in Bowling Green.

A dolomitic limestone was quarried some years ago at Mankato and Winona, Minn., for heavy masonry, bridge construction and building purposes. Rough construction stone is quarried at Mendota and Red Wing.

A pale buff to cream oolitic limestone is quarried for building uses at Cedar Park, Williamson County, Tex. Other producing districts in Texas are Lueders, Jones County, and Butler, Travis County.

Limestone is also quarried for building purposes in a small way in California, Illinois, Iowa, Kansas, Michigan, New York, Missouri, Ohio, Pennsylvania, Tennessee, Vermont, Virginia, Wisconsin, and Wyoming. It is also quarried in Puerto Rico.

PROSPECTING

Development work should not be started on a deposit without reasonable assurance that an abundant supply of limestone suitable for dimension stone is available. Generally it is deemed unwise to expend the large sum of money necessary to establish quarries and finishing plants unless a reserve for at least 20 years' operation is assured. Core drilling is usually desirable for determining the extent and quality of a deposit. As quality may vary in different beds, each one should be tested. The essential features, such as color, grain, and extent of beds, can be determined from the cores. No definite rules can be given for the position or arrangement of prospect holes. In Indiana they are spaced 100 to 300 feet apart, or closer in some instances. A log should be kept of the character of limestone found in each hole, and the cores should be marked and preserved for future reference. Depth of overburden may be determined by drilling or trenching.

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QUARRY METHODS

Quarrying and milling methods discussed herein are those employed in the limestone district of Indiana, but they are essentially the same in other districts.

Plan

Most deposits of limestone used as dimension stone are approximately flat-lying and of moderate thickness. Therefore, the stone available in any one opening may be removed within a short time, and a new ledge uncovered. Ledges are usually 120 to 140 feet wide - a width that can be served with a derrick boom. In large quarries a series of derricks is set in line, and a long ledge is worked down in a succession of floors until all the good stone is removed. The line of derricks is then moved back 130 to 140 feet, and another ledge is begun; thus, a whole area may be worked out in succeeding strips. Waste material from later operations is thrown into the openings previously made.

Stripping

In some places the overburden is stripped by power shovels. The hydraulic method is employed, however, when the surface contour is favorable for washing the soil into abandoned pits or other low-lying areas. This method is especially advantageous for washing clay from mud seams.

A second phase of stripping involves the removal of overlying noncommercial rock, which in some quarries may extend to a depth of 60 feet. The method of removal is governed chiefly by the nature of the contact of this rock with the underlying stone. Where it is separated by a layer of clay, shale, or a loose bed that serves as a cushion, it may be drilled and blasted with light charges of low-grade black blasting powder with little danger of shattering the good material. However, where the rock overburden is continuous with the stone of good quality, this process cannot be used, for powder cracks will extend into and destroy the good stone beneath. In such cases it may be necessary to channel the waste and remove it in block form - a stripping process almost as expensive as the removal of commercial stone. A unique process has been developed recently whereby a horizontal wire-saw cut is made at the base of the top rock. This artificial seam protects the stone beneath and permits removal of the top rock by blasting.

Channeling

Channeling machines make the primary cuts for block separation. The machine operates with a chopping action similar to that of a reciprocating drill and cuts a channel or narrow trench on one or both sides as it travels back and forth on a 7-foot 2-inch-gage track. The edge of the cutting tool is 1-7/8 to 2-1/8 inches wide and makes a channel about 2 or 2-1/4 inches wide. Cuts are 8 feet 4 inches to 8 feet 5-1/4 inches apart and may be 8 to 12 feet deep and 50 to 100 feet long.

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The cost of channeling ranges from 8 to 12 cents a square foot; it is, in fact, the largest single item of quarry cost and may amount to more than half the total cost.

Wire Sawing

The high cost of channeling has led some operators to attempt more economical methods of cutting. At least two companies in Indiana have used wire saws with fair success. One company made quite exhaustive tests in 1931. A cutting rate of 87 square feet an hour was attained, and the average cost was 13.9 cents a square foot. Details have been published by Newsom,5/ who directed the work.

Key-block Removal

In opening up a new floor where no free face is present, the removal of the first or key block is difficult. Sometimes it has to be broken up and removed as waste.

After an 8- by 8-foot block has been channeled on four sides, the tracks are shifted, and then two 2-foot blocks are channeled. The latter, known as "pulling" blocks, are usually comparatively easy to break loose by wedging in the channel cut. When a block is free, dogs or hooks are used to hoist it out. When one block is out of the way, floor space is provided for removing succeeding blocks, which are wedged free at the floor and removed one by one.

Another method of starting a new floor is to remove a mass 2 feet wide along the wall and make a long cut 20 feet from the 2-foot space and cross-cuts 4 feet apart. After the pulling blocks are removed, the 4- by 20-foot masses are turned down in the usual fashion.

Bed Lifting

Masses of rock that have been channeled are separated at the floor line by drilling and wedging. For this purpose, a series of holes 8 to 12 inches deep and 1 foot to 18 inches apart is sunk with air-driven hammer drills. They are not made at right angles to the wall but are inclined at such an angle that wedges placed in them may be sledged conveniently. Wedges are placed in the holes and driven in succession until a floor break is made.

Turning Down Blocks

After a block is wedged free at the floor it is turned down in a horizontal position before further subdivisions are made. Two notches or dog holes are made in the back channel cut to accommodate massive hooks, which are connected by means of sheave and tackle to another pair of hooks secured firmly on the quarry floor some distance in front of the block. A heavy

5/ Newsom, J. B., Results of Wire-Saw Tests: Trans., Am. Inst. Min. and Met. Eng., 1932, pp. 117-121.

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strain exerted on the cable by a derrick hoist gradually pulls the block over. Large wedges may be sledged in the back channel cut to assist the process. Piles of loose rock, "pillows," are placed to break the fall, so that the block comes to rest with little impact and without danger of breaking. Masses thus turned down are usually about 60 feet long, 12 feet high, and 4 feet wide.

Block Subdivision

The next step is to divide the mass into sizes for commercial use. Blocks are laid out with carpenter's square and straightedge. Where two or more grades of rock are present longitudinal breaks are made between them. Holes are first drilled in line 6 to 8 inches deep and 12 to 18 inches apart. Fractures are then made by the "plug-and-feather" method. The "feathers" consist of strips of iron, which are flat on one side for contact with the wedge and curved on the other to fit the wall of the drill hole. Two are placed in a drill hole, and a "plug" - a steel wedge about 6 inches long - is driven between them. They are sledged lightly in succession until a fracture appears. Blocks are commonly 10 by 4 by 3 feet and 10 by 4 by 4 feet.

Hoisting

Steel or wooden derricks of about 30 to 50 tons capacity are used for hoisting blocks from quarries. Derricks now in use have masts 80 to 110 feet high and booms 70 to 100 feet long. They are the swinging-boom type and are supported by 10 to 15 guy cables secured to deadeyes in the rock or attached to buried timbers. The end block is raised about 3 feet at the outer end and lowered again to the floor. This operation crowds it outward and makes a space of a foot or more for attachment of dogs. Heavy hooks (dogs) are inserted into the "dog holes" cut on opposite sides of a block, and a chain passed through the eyes of the hooks draws them firmly against the block, thus holding it securely for lifting. Blocks are removed in succession and placed on cars or piled for later disposal. Positions for attachment of dogs should be carefully chosen so that blocks may be exactly balanced. Each block is numbered or lettered to indicate its classification and for office records.

Storage and Transportation

Large storage capacity is essential, for enough stone must be accumulated during summer months to supply the demands of the four winter months when quarries are idle. Outdoor storage or "stacking yards" may be maintained at quarries or mills or at both places. A common method is to pile blocks within reach of derrick booms. They are usually piled high in a small space, and it is sometimes difficult to sort them. Some operators prefer overhead-traveling-crane storage, because the blocks may be handled more quickly. Standard railway cars and locomotives almost invariably are used for haulage.

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Scabbling

Quarry companies that operate mills use rough, untrimmed quarry blocks. If no local mills are operated, the blocks may be shipped long distances, and they must be trimmed carefully to avoid freight charges on waste. The trimming process is called "scabbling." Several methods are employed.

Scabbling picks similar to the ordinary double-pointed miner's pick are used to remove all irregularities. They are used, also, to remove corner masses from blocks to be turned into columns. Many operators prefer scabbling saws of various types because they leave a smooth, even surface and in a single operation remove large projections, which by the pick method are taken off piecemeal. Diamond-tooth drag saws are used singly or in parallel pairs adjustable for width. Diamond-tooth circular saws cut rapidly and, if mounted in pairs adjustable for spacing, may scabble both sides of a block at one time. However, the depth of cut is a limitation; a 60-inch saw can cut only 26 or 27 inches and a 72-inch saw, 32 or 33 inches. This difficulty is overcome by making one pair of cuts to the maximum depth the saws will reach and then turning the block over and cutting from the reverse side. If the cuts fail to meet, the intervening rock may be broken easily.

Scabbling planers are effective substitutes for saws. They consist of two sets of massive vertical blades, which scrape off irregularities as a block passes between them on a bed. By screw-feed adjustment the blades are set closer after each cut until a smooth surface is obtained. On blocks 6 feet high, each cut removes one-fourth inch of rock, and on blocks 4 feet high one-half inch. About three blocks may be scabbled in an hour by this method.

A wire saw consisting of a 3/16- or 1/4-inch 3-strand cable running as an endless belt driven by an electric motor is also used for scabbling. Several blocks may be lined up and cut at the same time. The equipment may be operated by one man, and an average cutting rate is 20 to 25 square feet an hour.

MILLING METHODS

Some limestone companies quarry only, others also maintain mills where the stone from their quarries is sawed into slabs or manufactured into finished forms, whereas still others operate only mills and buy their rough material for fabrication.

Drafting and Pattern Making

Before any cut-stone job can be started, accurate detailed drawings must be made of every piece of stone to be used that differs from another in size or shape. The cost of the drafting work required for a large structure may be one-half to two-thirds as much as the entire quarry expense of supplying rough blocks of stone. Architects' drawings usually are insufficient, for the stone must be fitted accurately to the steel framework, and detailed data on the size and position of each steel member are necessary

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before stone workers' shop drawings can be made. Some sizes may be duplicated many times in a building; others may be used only once or twice.

Patterns for molded and carved work are made of zinc or other soft metal, or sometimes paper patterns or stencils are used, the design being transferred to the stone surface by dusting burnt umber through perforations. For the most intricate carved work plaster models are used.

Ticket System

After shop drawings are made, draftsmen prepare for every block of stone a ticket on which is a drawing of the block with exact dimensions indicated. The ticket is numbered, and if a pattern is to be used its number also is shown. The man in charge of gang sawing first gets the ticket and cuts the block or slab. As this passes to the planer, jointer, and all subsequent machines, the ticket goes with it, and each workman consults it before any work is begun. By this means workmanship is constantly verified, and very few mistakes occur. Great care and skill are required, for one small error may ruin a block.

Block Handling

Mills are of two types. One is wide and equipped with two pairs of crane tracks. A heavy crane for placing quarry blocks on saw beds travels on one track, and on the other is a lighter and more rapidly moving crane for conveying smaller blocks as they pass from one operation to another. The crane almost universally used is the overhead traveling type with at least a 70-foot span.

The other type of mill is long and narrow with one pair of tracks on which several cranes operate. There may be a 25-ton-, 15-ton-, and 7-1/2-ton-capacity crane working at the same time. Most of them are of the 2-motor type, one motor with two friction clutches serving for both lateral motion and hoist.

Railway tracks for transporting quarry blocks to mills and shipping finished products enter across the end, down one side, or across the middle of the building. Rough blocks and single unfinished slabs are handled with grabhooks; finished and semifinished blocks or piles of slabs, with cable slings or with slings of rubber belting so as to avoid damage to corners and edges.

Operators travel back and forth in cabs attached to the crane. Two men called "hookers" attach and release hoisted blocks and signal the craneman.

Sawing

The first step in manufacture is to saw rough blocks to required dimensions. Gang saws of various sizes are used almost universally for this purpose. They consist of a series of soft steel blades set in parallel

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positions in a frame which has a backward-and-forward swinging motion. As the frame moves, actuated by a crank and connecting rod (pitman), the cutting blades lift toward the end of each stroke. This permits the abrasive, usually sand, to wash under them, and as they start back on the return stroke they bear down on the sand and abrade the rock rapidly. An adjustable automatic gear feeds the gangs downward at any desired rate. Steel shot is used as abrasive when a deeply scored, "ripple-mark" surface is desired. The average cutting rate is about 6 inches an hour. The blades may be spaced for thin slabs or thick blocks.

Another type, a straight steel blade with diamond teeth on the lower edge, is used as a drag-saw for making single cuts. A drag tooth is mounted with six diamonds of about 3/4-carat size placed in alternate positions on opposite sides of the cutting face. This saw will cut at a rate of 30 to 40 square feet an hour.

For making subsequent cuts, circular diamond saws are used almost invariably. The blades are steel, one-fourth inch thick, with a series of square notches around the rim. Steel teeth mounted with diamonds are set in the notches and held in place with copper rivets.

A heavy service type known as a "ripsaw" has a stationary mounting, and a bed actuated with a worm gear carries the block of stone beneath it. Teeth for ripsaws are supplied with two 1/2- to 5/8-carat diamonds. A jointing saw designed for smaller cuts and similarly mounted is provided with teeth, each of which has 6 to 10 small diamonds. A stream of water cools the cutting edge of a diamond saw and carries away the cuttings. The sawing rate is 3 to 16 inches a minute, depending on the depth of the cut. The most exacting workmanship is exercised in the manufacture of diamond circular saws to insure accurate balance, uniform cutting, and true running. Each saw is designed for a standard speed and should be run at no other. Speeds range from 11,000 to 13,000 surface feet a minute. With care a saw will perform constant service for 6 months to a year without being conditioned. Although the price of a diamond saw is high, it cuts rapidly, and maintenance cost is low.

Silicon carbide (carborundum) circular saws give excellent service for the smaller cuts because they leave smooth surfaces and are less liable than diamond saws to chip the corners of blocks.

Planing

Planers are used for cutting stone blocks and slabs to smooth surfaces and desired thicknesses and also for cutting moldings and shaping curved designs. The frame that holds the cutting tool has lateral and vertical motion actuated by power-driven worm gear and may cut the tops and sides of a block simultaneously. As a block of stone is carried beneath a planer on a traveling bed called a "platen" at a rate of 30 to 45 feet a minute, the cutter scrapes a thin layer from the surface. Cutting tools are shaped to fit molding designs; that is, the tool is the reverse of the pattern.

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When curved designs are to be cut, the stone is placed on a second bed or platen resting on the regular planer bed and capable of rotating through an arc of a circle. This second platen is guided by an arm, pivoted to one side of the planer, whose length governs the curvature of the arc.

A carborundum planer consists of two saws with a drum of smaller diameter between them. The saws trim the sides of slabs while the drum smoothes the upper surfaces. The planer bed travels at a rate of only 20 to 30 inches a minute but finishes the job in one cut, thereby accomplishing much more in a given time than an ordinary planer.

The accomplishment of a planer is equivalent to that of seven stonecutters using hammers, chisels, and modern pneumatic tools.

Turning and Fluting

Large columns are first scabbled in cylindrical shape and then mounted in lathes, where they rotate against a tool traveling slowly back and forth over the full length of the stone. The tool is actuated by machine-driven worm gear and may be adjusted for any diameter by a screw feed. A smooth surface is obtained by this process, but final rubbing is usually done by hand.

The fluting process is also carried out on a lathe. The flutes are drawn with pencil or crayon on the surface of the column, and the fluting tool attached to the tool post of the lathe travels back and forth while the column remains stationary. This process is continued until the line bounding the flutes is reached. If a column is tapered, the flutes may be cut shallower on the smaller parts of the column, and this automatically makes them narrower. When a flute is completed, the column is rotated with a hand bar, and the process is repeated in the new position. The ends are finished with pneumatic tools, and the column is rubbed by hand.

For making balusters, particularly if many of one kind are to be fabricated, a carborundum wheel cut as a negative of the pattern is generally used.

Milling

"Milling" is a term applied in a general way to all mill processes, such as sawing, planing, cutting, or carving, but it specifically refers to the operations of a milling machine by which irregular patterns are cut in stone. Milling is particularly advantageous in preparing for the carvers blocks in which deep recesses are to be cut, for it removes the bulk of the stone much more rapidly than do hand processes. The machine consists essentially of a rotating head, which carries cutting tools of various sizes and shapes. It has right-and-left as well as vertical worm-gear motions, and a movable platen provides backward-and-forward motions.

Cutting and Carving

Cutting usually is defined as straight-line work and carving as curved work. Carving requires much skill and is generally done by experienced workmen. The work is now done, for the most part, with pneumatic tools -

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heavy ones for removing the larger fragments and smaller ones for completing designs - but a chisel and mallet are still necessary for certain operations. Patterns are used for the designs and models for the complicated figures.

Oolitic limestone may be carved more easily than most other building stones and therefore can be finished at a cost that permits extensive use.

Finishing

Various types of surface finish are achieved by the use of different kinds of tools. A tooled surface, which is one covered with fine grooves in parallel lines, is made with a pneumatic or planer tool having fine teeth. A bush-hammered surface is rough and pitted, the hammer used having a face covered with small projections. A hand-picked surface is covered with indentations made with a sharp-pointed tool. A small-fluted surface is covered with small parallel corrugations. A four-cut surface is made with a planer tool having four corrugations to the inch. A rubbed surface is smoothed by hand-rubbing with sand and water or some other abrasive. A shot-sawed or ripple surface is deeply scored or grooved by using steel shot as abrasive for the gang saws. Chat-sawed stone is smoother than the shot-sawed stone.

MARKETING

Dimension stone is sold by the cubic foot, and much of it commands a price sufficiently high to give it a Nation-wide market. From two-thirds to three-fourths of all building limestone is sold as rough blocks or sawed slabs to mills in consuming centers, where it is fabricated chiefly for small or moderate-size buildings. The balance of the production is manufactured for specific projects, usually of large size, in mills operated in conjunction with quarries or in independent mills. These mills, supplied only with shop drawings, can furnish, for a structure many miles away, thousands of blocks of limestone in exact dimensions, each fitted accurately for its particular position in the wall. The smaller limestone quarries, for the most part, sell their stone to local builders and contractors.

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